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The Advanced Photovoltaic Solar Array (APSA) Technology Status and Performance

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Introduction

In 1985, the Jet Propulsion Laboratory, under sponsorship of the NASA Office of Astronautics and Space Technology, initiated the Advanced Photovoltaic Solar Array (APSA) program. The program objective is to demonstrate a producible array system by the early 1990s with a specific performance of at least 130 W/kG (beginning-of-life) as an intermediate milestone towards the long range goal of 300 W/kG. The APSA performance represents an approximately four-fold improvement over existing rigid array technology and a doubling of the performance of the first generation NASA/OAST SAFE flexible blanket array of the early 1980s.

Technology Status

The first phase of the APSA program developed preliminary designs through contracts with TRW and LMSC. In order to allow for a subsequent comparison and evaluation of the two designs a number of ground rules were established through a consensus agreement. These requirements established the operational environment for the array design (geosynchronous-10 years lifetime), the baseline size (approximate 10 kW with scaleability from 5 to 25 kW), and a number of additional mechanical and electrical characteristics. At the completion of the design phase, TRW was selected to implement prototype hardware development. The prototype hardware effort was identified as phase II. Due to funding constraints phase II was divided into an A and B effort. Phase IIA began in 1987 and was completed in 1988. Phase IIB began in January, 1989, and is expected to be completed in early 1990. A schedule for phase IIB is shown in figure 1. An additional phase will be added to develop any necessary array upgrades and to perform ground testing and evaluation.

The prototype hardware being developed during phase II is essentially a foreshortened version of the approximately 5 kW TRW wing design developed during phase I. The configuration of the APSA is similar to the SAFE array flown on the shuttle in 1984; it is a flexible fold out wing with deployment and structural support attained through the use of a rear side mounted coilable longeron mast. The APSA wing design is based on a flexible foldable blanket element called a SPA, or solar panel assembly. The full size wing consists of 13 SPAs, each covered with 5760 thin 2x4 cm^2 silicon solar cells. The prototype wing will include two SPAs and the mast is reduced in length accordingly. Cell coverage is reduced to a total of 1440 cells with the remaining SPA areas covered by mass simulating aluminum wafers. The lid and pallet structure (also referred as the blanket housing) and the mast canister are equal in size to the full scale wing design. A sketch of the prototype wing is shown in figure 2.

During phase IIA, the flexible blanket, consisting of two SPAs, along with additional leader, or lid/pallet attachment, panels was successfully assembled by TRW. Thin silicon cells were provided by all three space solar cell vendors, ASEC, Solarex, and Spectrolab, and 50 micron thick CMZ glass cell covers were provided by Pilkington. In addition a lightweight canister/mast system was provided by AEC Able Engineering. Appropriate tests were performed on all assemblies to verify mass estimates and mechanical performance projections.

At present phase IIB is well underway. As shown in figure 1, the remaining tasks include fabrication of the blanket housing (lid/pallet structure and tiedown/release mechanisms), integration of all wing components, and a ground deployment to verify prototype form, fit, and function. Component development tests have recently been completed on a narrowed version of the blanket housing. These tests included an exposure of the latched housing to an acoustic environment 6 db higher than present shuttle requirements. No structural problems were identified and the blanket housing test article has been subjected to repeated latch and unlatch tests prior to and after testing without any anomalous results. A photograph of the blanket housing test hardware is shown in figure 3. As a result of these tests, fabrication of the full size blanket housing has commenced.

A key demonstration for the integrated wing will be a ground deployment which will verify the unlatching of the tie down mechanisms and the deployment of the mast/blanket system. Particular care is required in conducting such a test in the earth's gravity environment. Consequently, a fixture has been prepared to support the wing assembly both during the stowed and deploying phases. The fixture has been designed to minimize frictional forces on the wing supports which would otherwise interfere with the deployment. Figure 4 is a photograph of the fixture with the APSA blanket attached. Mockup lid and pallet endplates are attached for a manual deployment (without the mast/canister assembly) to verify low friction blanket motion.

One additional test which is presently underway is being supported by NASA-LeRC. A small module fabricated by TRW to the APSA blanket design is undergoing extensive thermal cycling in the LeRC fast thermal cycling chamber. At present 3000 GEO type thermal cycles have been completed without significant electrical change.

The module is presently being subjected to an additional LEO type thermal cycles. To date 18,000 of the LEO cycles have been completed without any degradation.

APSA Performance

At the end of the phase I design effort array electrical and mechanical performance estimates were made for a ten year geosynchronous mission. These have been updated to include the results of hardware fabrication and design changes in the phase II effort. Table 1 shows both sets of performance estimates along with the initial phase I contract performance goals. The result of the phase II work has been to increase both wing power and mass somewhat (for example, a slightly thicker and more efficient silicon cell is presently used). Although there has been some reduction in APSA specific performance it still exceeds the goal of 130 W/kG. It should be noted that the mass and specific performance values include a ten percent contingency. Part of that contingency is due to design uncertainty and will be reduced when the prototype hardware is completed.

The APSA electrical performance has been examined for two missions which would benefit from the use of a lightweight array. These include the initial GEO orbit and a LEO-GEO transfer orbit as might occur with solar electric propulsion. Table 2 presents results for a ten year GEO mission and compares the baseline APSA design (3 mil shielding front and rear) with some options. The options include a more heavily shielded APSA, a conventional rigid array (using thin silicon cells), and an extrapolation of APSA using thin film copper indium diselenide(CIS) cells rather than silicon cells. It should be noted that the CIS option is based upon preliminary data obtained with development cells. However it does serve to indicate what is possible with the use of a relatively moderate efficiency, radiation resistant, thin film cell, even if such a cell eventually is composed of some other material. For the GEO application it is clear that no significant benefit follows from increased APSA shielding or the use of rigid array technology. Both provide for a modest reduction in array area, but both incur a significant mass penalty. The use of the advanced thin film material cell will, in contrast, save mass and area and probably cost.

A more dramatic result is seen in table 3, where a similar analysis is performed for a possible LEO-GEO transfer lasting 200 days. The transfer orbit was calculated by assuming the performance of a solar electric ion propulsion system. In this case increased APSA shielding will lead to fairly substantial reductions in required array area, as will the use of a conventional rigid array. These area reductions will most likely provide for array cost reductions. However, in all cases the baseline APSA array will still be the lightest option, an important factor for a SEP mission where increased array mass will require a corresponding decrease in payload, or an increased transit time which would in turn lead to further array degradation. The best option is that of the APSA using the thin film cell, for not only is it the lightest but it also has the least area. The importance of the development of such lightweight cells for future APSA versions is clear, particularly where substantial radiation will be experienced.

Flight Readiness

The present APSA program has as its objective, the ground testing and verification of a prototype lightweight wing assembly. The prototype is not intended to be flight hardware, inasmuch as program constraints could not support flight hardware fabrication. At the same time, the fabrication of the prototype has been accomplished with sufficient design development to address potential manufacturing difficulties and identify any unsuspected design weaknesses. As a result it is felt that design maturity will be sufficient to allow for a subsequent flight design and manufacturing effort. Figure 5 is a suggested schedule for flight hardware effort that could commence at the end of phase III. Obviously a number of assumptions are included since any actual flight application will have its own unique set of requirements. The schedule is for the fabrication of a single wing of the present APSA size (5.8 kW) and includes detail design task to meet flight requirements and appropriate qualification testing. It is estimated that an additional wing could be fabricated by adding an additional 4-6 months of schedule time. Allowing one year for the procurement cycle suggests that the APSA type lightweight wing could be ready for launch in the mid 1990s.

Conclusion

The APSA is nearing completion of the prototype fabrication and ground test effort. It is likely that the specific power goal of 130 W/kG or greater will be achieved. A flight test could be possible by the mid 1990s.

Lightweight and relatively radiation resistant arrays can provide significant advantages over conventional rigid arrays for a number of mission applications, both in BOL and EOL(end- of-life) performance. The development of advanced lightweight thin film, radiation resistant, solar cells is key to extending the advantages of the present APSA technology well into the next century. Such cells may allow future arrays to provide EOL specific power values appreciably higher than present day BOL values.

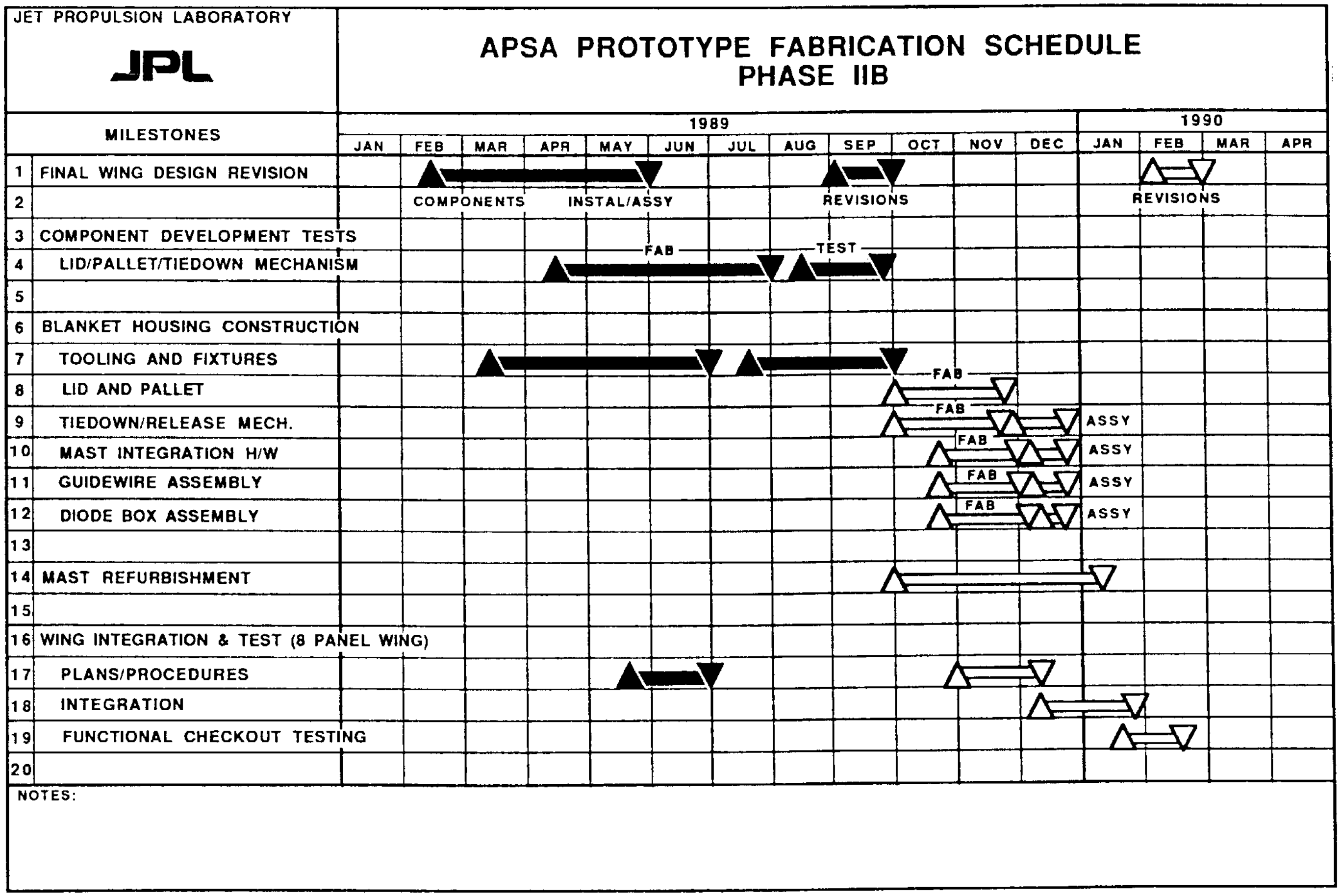

Figure 1: APSA Prototype Fabrication Schedule Phase IIB

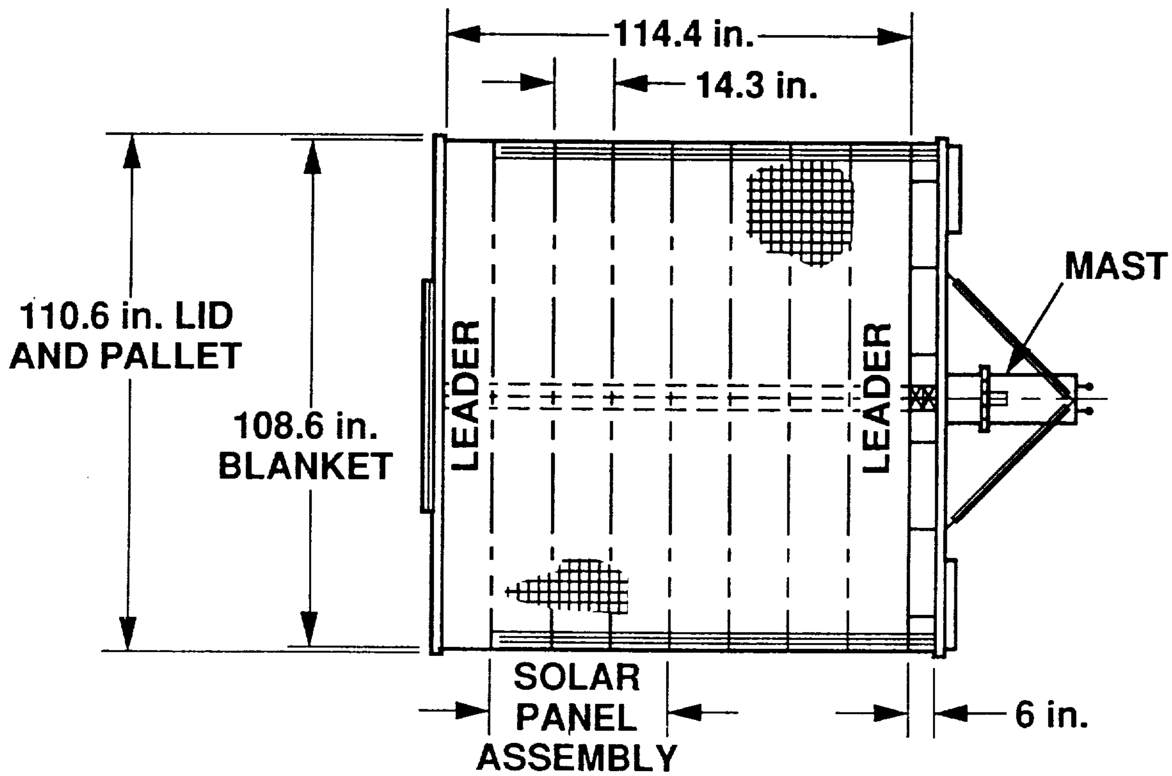

Figure 2: APSA Prototype Wing Configuration

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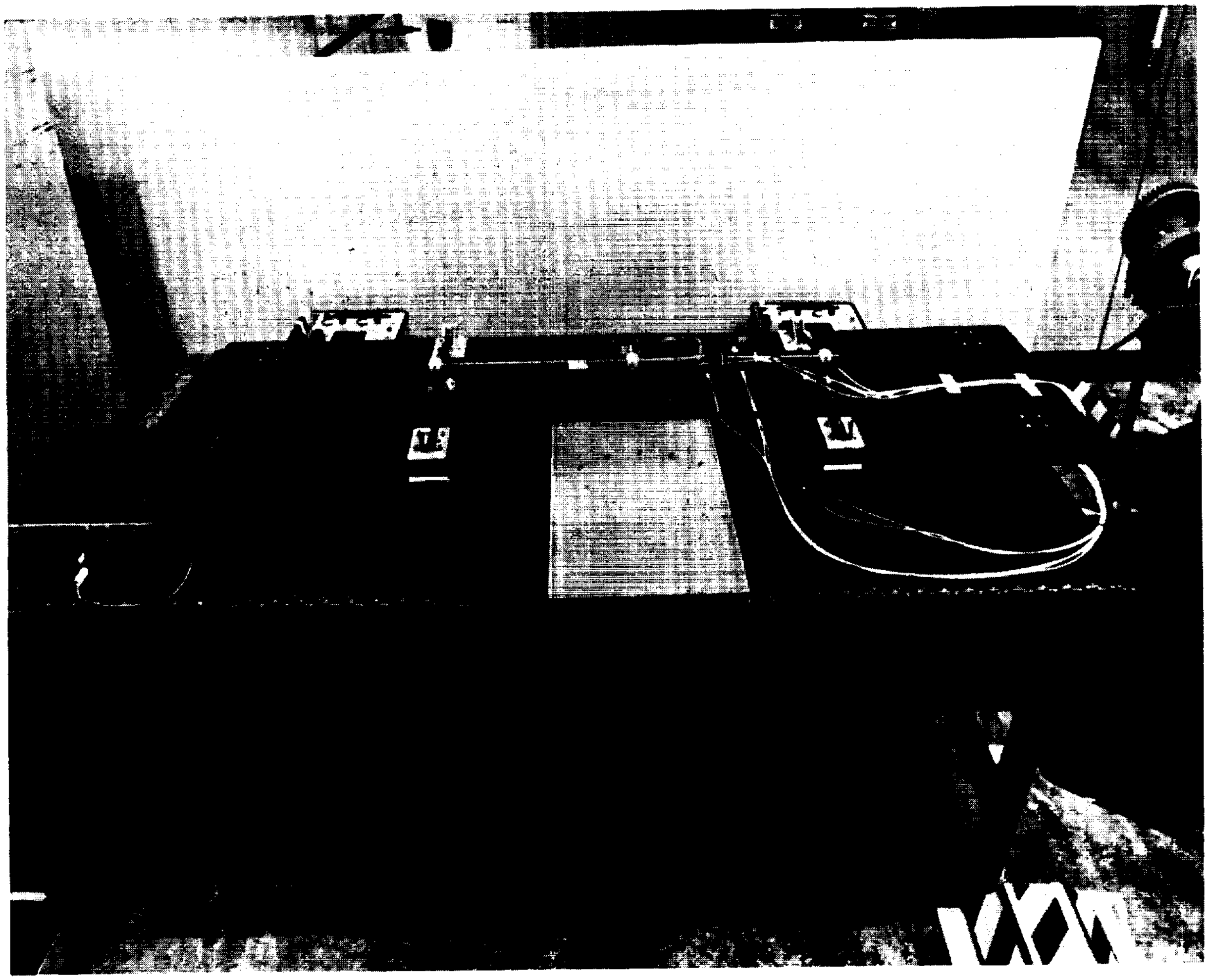

Figure 3: APSA Blanket Housing Development Test Hardware

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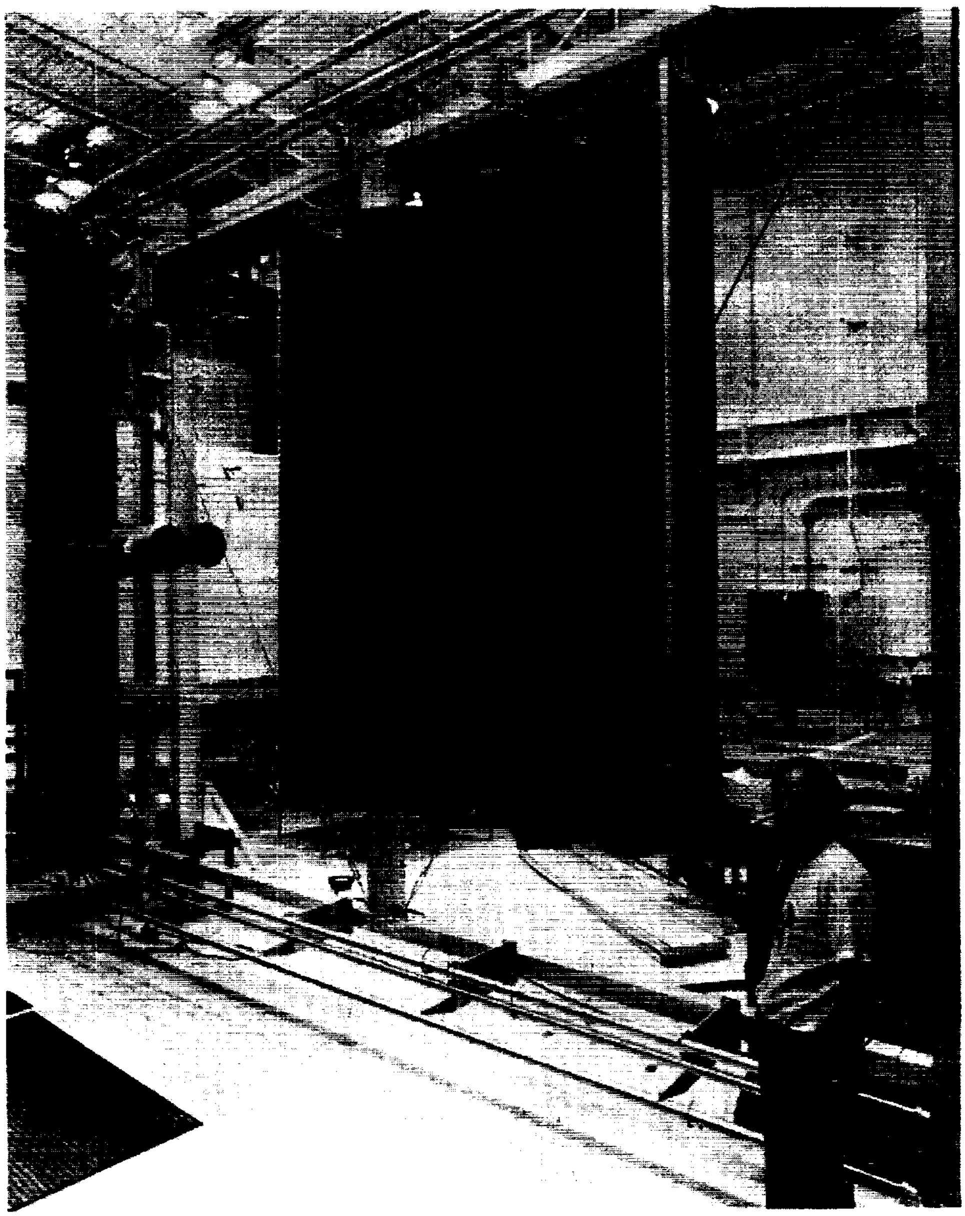

Figure 4: APSA Prototype Blanket on Deployment Test Fixture

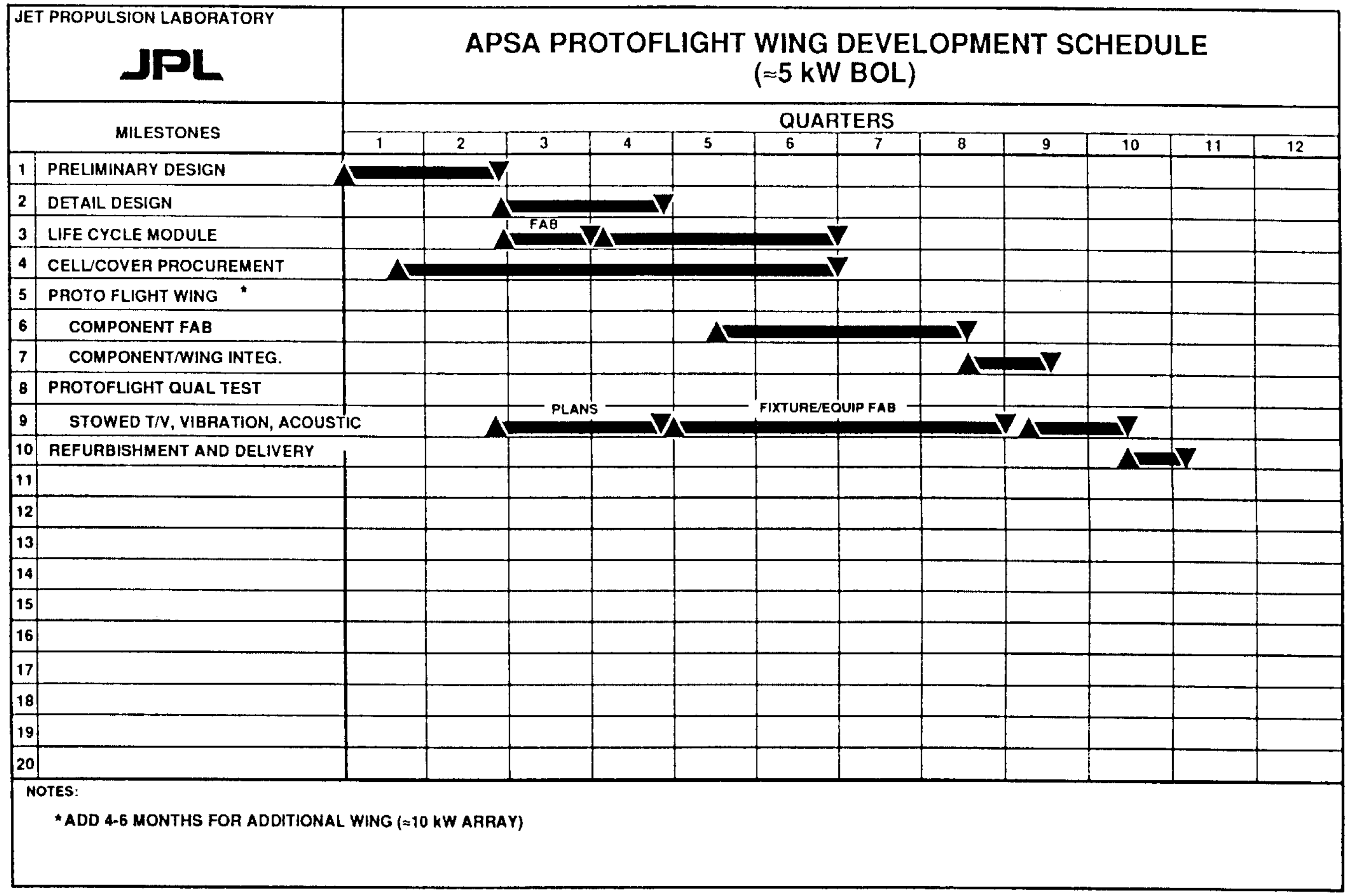

Figure 5: Baseline Schedule for APSA Flight Test Wing

PARAMETER	1986 GOAL	PHASE I 1986 ESTIMATE	PHASE II 1989 ESTIMATE
BOL POWER (GEO)	10 kW (2 WINGS)	10.4 kW	10.6 kW
EOL POWER (GEO)	NOT SPECIFIED; 8 kW IMPLIED BY EOL SPECIFIC POWER GOAL	7.4 kW	7.7 kW
BOL SPECIFIC POWER AT EQUINOX	>130 W/kg	136.1 W/kg*	131.5 W/kg*
EOL SPECIFIC POWER AT EQUINOX	>105 W/kg	96.7 W/kg*	93.8 W/kg*
EOL POWER DENSITY AT EQUINOX	>110 W/m_2; REFERENCE AREA NOT SPECIFIED	94.6 W/m_2**	98.9 W/m_2**
BOL OC VOLTAGE	<200 volts	210 volts	214 volts
WING WEIGHT	NOT SPECIFIED	38.2 kg*	41.1 kg*
DEPLOYED FREQUENCY	>0.01 Hz; 0.1 Hz PREFERRED	0.10 Hz	0.14 Hz (BENDING) 0.12 Hz (TORSION)
DEPLOYED STIFFNESS	>0.001 g; 0.01 g PREFERRED	0.015 g	0.015 g

* INCLUDES 10 PERCENT WEIGHT CONTINGENCY

** BASED ON TOTAL PANEL AREA WITH HARNESS

Table 1: APSA Electrical and Mechanical Performance

	SPECIFIC PERFORMANCE (W/kg)		RELATIVE AREA FOR SAME EOL POWER (≈7 kW)
	BOL	EOL	
APSA (3 mil SHIELD) *	130	94	1.00
APSA (6 mil SHIELD) *	95	73	0.94
CONVENTIONAL RIGID (12 mil COVER)	25	20	0.90
APSA ($CuInSe_2$)** EST.	165	155	0.95

* FRONT AND REAR SIDE EQUIVALENT SHIELDING
** ASSUME 11% CELL EFFICIENCY, 3 mil SHIELDING FRONT AND REAR, SILCON DAMAGE EQUIVALENCE

Table 2: APSA Specific Performance 10 Years GEO

	SPECIFIC PERFORMANCE (W/kg)		RELATIVE AREA FOR SAME EOL POWER (≈7 kW)
	BOL	EOL	
APSA (3 mil SHIELD) *	130	50	1.00
APSA (6 mil SHIELD) *	95	45	0.81
APSA (12 mil SHIELD) *	65	38	0.63
CONVENTIONAL RIGID (12 mil COVER)	25	17	0.57
APSA ($CuInSe_2$)** EST.	165	130	0.56

* FRONT AND REAR SIDE EQUIVALENT SHIELDING
** ASSUME 11% CELL EFFICIENCY, 3 mil SHIELDING FRONT AND REAR, SILCON DAMAGE EQUIVALENCE

Table 3: APSA Specific Performance - 200 Day LEO to GEO Spiral Orbit